SEAWASP: A PROTOTYPE SYSTEM FOR SHIPBOARD ASSESSMENT BASED ON IN SITU ENVIRONMENTAL MEASUREMENTS

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Introduction

This paper describes a prototype tactical decision aid called SEAWASP (Shipboard "Environmental Assessment/WeApon System Performance), developed by the AEGIS Shipbuilding Program to demonstrate the feasibility of in situ estimation of radar and weapon system performance. The need for this capability has been made clear by the wide range of radar performance experienced by AEGIS ships in operational exercises and confirmed in post-test analyses during the past 12 years. AN/SPY-1 track initiation ranges have been observed to vary by factors of two or more for the same target due to atmospheric conditions; surface clutter conditions have also been seen to vary enormously. Both of these effects are most severe in particular littoral environments where strong refractive inhomogeneities are prevalent due to land influences and land backgrounds result in large clutter returns. Furthermore, the importance of accounting for these effects is heightened as anti-ship missile threats develop toward increasing speeds and decreasing radar cross sections and altitudes.

The initial goal of SEAWASP is to aid in the selection of AN/SPY- 1 radar configuration parameters for the variety of environments encountered by AEGIS ships. Specifically, radar operators frequently reduce sensitivity to remove unwanted clutter tracks without being able to assess the associated impact on target detection and track capability. Large or extended surface clutter is often due to surface ducting conditions. In these situations, reducing radar sensitivity may be justifiable since the ducting also increases the power on low-altitude targets. However, in other cases this is not true and sensitivity could be reduced to a point where tracking performance is significantly degraded. SEAWASP makes radar operators aware of impacts on performance of radar configuration changes in the prevailing environment. In addition to aiding AN/SPY-1 configuration, SEAWASP can also aid in depth-of-fire assessments for weapons doctrine selections and in decisions regarding ship placement.

The development of SEAWASP was a natural outgrowth of earlier environmental characterization and system performance modeling efforts at JHU/APL associated with quantitative post-test analysis of AEGIS exercises. During these efforts a high-fidelity propagation model (References 1 through 4), environmental measurement techniques (References 5 through 7), and an AN/SPY-l simulation were developed and exercised extensively. In the course of this work, an ability to reconstruct signal levels within nominally 5 dB, and firm track ranges to within 10%, in the low-altitude region was demonstrated (Reference 2). These successes depended, however, on the acquisition of timely, high-resolution atmospheric data. Work is underway to quantify the resolution required for accurate propagation and radar performance predictions (References 8 and 9).

The approach to performance assessment used in SEAWASP was first demonstrated on an AEGIS cruiser, the USS LEYTE GULF (CG 55), in 1988. This work was reported during an NATO AGARD (Advisory Group for Aerospace Research& Development) meeting devoted to discussion of operational decision aids for dealing with propagation effects (Reference 10). The present SEAWASP program was initiated in 1992, and shipboard testing of the environmental data acquisition portion of SEAWASP began in 1993. Periodic testing aboard AEGIS cruisers, including the USS PORT ROYAL (CG 73) and USS LAKE ERIE (CG 70), has continued up to the present. The two SEAWASP systems currently installed on the USS ANZIO (CG 68) and USS CAPE ST GEORGE (CG71) are the first fully autonomous versions of SEAWASP, and will undergo at-sea evaluation for 9 to 12 months.

General System Description

A high-level depiction of SEAWASP as installed on CGS 68 and 71 is illustrated in Figure 1. SEAWASP is comprised of two primary subsystems: the Environmental Characterization and Radar Performance Assessment Subsystems. The former is described only briefly here since it is the subject of a companion paper in this conference. A description of Environmental Data Processing functions is shared between the two papers. The primary focus of this paper is the Radar Performance Assessment Subsystem.

The basic components of the Environmental Subsystem are two meteorological masts (met masts), rocketsondes, floatsondes, and a data acquisition/processing system. Each met mast contains a microprocessor controlled instrument package that measures air temperature, relative humidity, and wind speed/direction at a nominal height of 9 meters above the sea surface. The starboard met mast also includes a GPS antenna/receiver, a compass, and IR temperature sensors. The sonde receive antenna, used for both the rocketsondes and floatsondes, is mounted on the port met mast.

Acquisition, processing, management, and communication of environmental data are coordinated by the Control Manager program which runs on a RADISYS 486 processor board under the 0S/2 operating system. This processor board complies with the VME 6U standard adopted by the Navy and is installed in the NGP AN/UYQ-70 (Next Generation Peripheral) console in the ships' computer rooms (Computer Central). This subsystem produces refractivity profiles that characterize propagation conditions in the ship's vicinity. The processing algorithms include surface layer (evaporation duct) models, data smoothing/assimilation/quality control algorithms, and expert-system procedures which monitor changing conditions and are planned to make automatic recommendations regarding rocketsonde and floatsonde deployment. Processed data from met masts and floatsondes are used primarily for evaporation duct estimation, while temperature/pressure/humidity profiles from the rocketsonde system characterize refractive structures above the evaporation duct. These data are "blended" to form a complete characterization of the refractivity profile in the ship's vicinity. The remainder of the Environmental Subsystem processing functions are described in the companion paper.

As seen in Figure 2, the Radar Performance Assessment Subsystem is comprised of a propagation model (TEMPER), an AN/SPY-1 radar performance model (FIRMTRAK), server programs which control data flow and model execution, and a Human-Machine Interface (HMI). Functionally, this part of SEAWASP accepts refractivity profiles from the Environmental Subsystem and computes and displays AN/SPY-l performance estimates for the prevailing local environment, based on 'live' radar settings and selected target options. Some of these radar settings are chosen automatically by the combat system, not by an operator. SEAWASP also provides the capability for an operator to enter trial radar doctrine and manually initiate performance assessments. Results are automatically displayed along side the performance assessments based on the 'live' radar settings.

Most of the development effort for the Performance Assessment subsystem focused on designing and implementing the HMI and client-server processes, integrating tactical AN/SPY-1 radar settings via existing ship systems, and configuring hardware and software for robust, autonomous shipboard operation. Propagation and AN/SPY- 1 radar models were taken from proven versions used for in-house analysis with no substantial modification.

The Radar Performance Assessment portion of the system runs on three HP 743i processors, each with a dedicated 2-gigabyte hard disk, and an X-station. The processors are in the VME 6U form factor, are mounted in the NGP AN/UYQ-70 console, and run under the HP-UX operating system. The X-station and trackball are mounted above the SPY-1 RSC (Radar System Controller) console in CIC (Combat Information Center) as shown in Figure 3. The X-station in CIC is needed since the RSC console in Baseline 5 Phase 1 is not MOTIF/X-Windows compatible. The processors and X-station communicate via a SEAWASP ethernet LAN (Local Area Network).

The two AEGIS ships currently hosting SEAWASP also have an experimental tactical display system called the Command Display & Control System (CDCS), prototype to the AEGIS Display System MK 6 presently under development. CDCS can drive two of the four large-screen -displays in CIC. The CDCS experiment also includes installation and operation of the Navy's new MOTIF/X-Windows capable AN/UYQ-70 consoles in CIC. SEAWASP's access to the 'live' radar settings is via a router connection to the CDCS display LAN. In addition to making combat system data available, this connection opens the potential for the MOTIF-compatible SEAWASP displays to be available to all of the AN/UYQ-70 consoles in CIC.

<u>Propagation Model (TEMPER)</u>

SEAWASP presently relies on the Tropospheric Electromagnetic Parabolic Equation Routine (TEMPER) to calculate RF propagation factor (References 1 through 4). TEMPER calculates propagation factor based on refractivity profiles supplied by the Environmental Characterization Subsystem. An input file specifies antenna and frequency parameters corresponding to the lowest beam position of the AN/SPY-1 radar. TEMPER calculations are performed for the lowest 1500 feet of the atmosphere and out to 128 nautical miles in range. These parameters are chosen to support the current SEAWASP implementation which estimates AN/SPY- 1 performance for low-elevation targets.

The intention is to eventually replace TEMPER with the Navy Standard propagation model, RPO (Radio Physical Optics) when it is upgraded to achieve TEMPER's fidelity for the low elevation region. With the speed of a hybrid program like RPO, SEAWASP could address the full AN/SPY- 1 coverage space. Also, as propagation over land is introduced, models such as the Advanced Propagation Model (APM), currently under development by the Navy, will be implemented.

<u>AN/SPY- 1 Firm Track Model (FIRMTRAK)</u>

The FIRMTRAK program uses an event-driven, Monte Carlo simulation to represent track initiation, track maintenance, and drop track processes of AN/SPY-1. FIRMTRAK randomly varies several parameters, such as target altitude, on each Monte Carlo iteration to accumulate probabilities of tracking a target. System noise and target RCS parameters are represented by multiple draws from a random number generator. Other relevant parameters in FIRMTRAK include transmit power, transmit gain, beam-shape loss, search frame time (SFT), . . waveform mode, baseline sensitivity, sensitivity time control (STC), pulse compression, and TEMPER-generated propagation factors. The elevation beam shape, antenna height, pointing direction, and of course, environmental effects, enter via the TEMPER propagation factor.

SEAWASP calls FIRMTRAK from a main program designed to represent the AEGIS Baseline program currently on CGS 68 and71, Baseline 5 Phase 1. This main program accepts AN/SPY-l parameters for baseline, sector, and subsector regions and creates the appropriate number of input sets for FIRMTRAK to represent performance for 360 degrees around own-ship Results are displayed as ranges from own-ship corresponding to 10%, 50%, and 90% probability of firm track. Differences in the 10%, 50%, and 90% ranges are an indicator of the sensitivity of the calculation. Track drops and re-acquisitions are represented to indicate track continuity.

Human-Machine Interface (HMI)

SEAWASP's HMI designed leveraged off of concepts and layouts already familiar to SPY operators while maintaining compatibility with developing AEGIS combat system display conventions and allowing for future growth into planned assessment capabilities. Lessons learned from at-sea evaluations of a previous SEAWASP display design were also incorporated into this version of the HMI.

The SEAWASP HMI indicates embedded hardware and software status information, permits configuration of radar and threat parameters, provides for initiation and display of performance assessments, and allows communications with rocketsonde and floatsonde launch systems. It is comprised of the following five panels: 1. 'Status Message' Panel, 2. 'System' Performance Assessment' Panel, and 3. 'Operator' Performance Assessment Panel, 4. 'Rocketsonde Launch' Panel, 5. 'Floatsonde Launch' Panel. The default display includes the first three panels (Figure 4). The following paragraphs provide a high-level description of the primary functions and options of the default panels.

'Status Message' Panel

The 'Status Message' panel (left-most panel) has three modes: Environmental, System and Operator. The Environmental mode indicates the health and activity of hardware and software in SEAWASP's Environmental Characterization Subsystem. Hardware messages are indicated as "OK" or "Not Responding" for the compass, GPS, IR surface and cloud sensors, and the port and starboard met mast microprocessors, temperature and humidity sensors, and anemometers. The need to change the desiccants in the port or starboard met mast instrumentation packages is also indicated. Environmental Software Status Messages indicate when the data acquisition programs for met masts (MAST), rocketsonde (ROCKET), floatsonde (FLOAT), and the processing programs for evaporation duct modeling (EVAP DUCT), and Rocketsonde/Evaporation Duct merging (RED) are "Active" or "Inactive".

Several Alert Messages can appear automatically in the lower part of the 'Status Message' panel. These alerts can indicate rocketsonde or floatsonde launch requests ore a variety of error conditions. Requests to launch rocketsondes or floatsondes are entered via a small, hand-held I/O terminal from the aft VLS deck. This 170 terminal consists of an integrated display and key pad and plugs into the starboard met mast instrumentation package during rocketsonde and floatsonde launches. Because rocketsondes and floatsondes use the same receiver, they cannot be operated simultaneously. An attempt to do this triggers alert error messages.

The purpose of the System and Operator modes of the 'Status Message' panel is to indicate, sector by sector, warnings for performance displays in the corresponding Performance Assessment Panels. Because the functionality and layout of the 'System' and' Operator' Performance Assessment panels are very similar, their associated 'Status Message' panel modes are functionally identical.

'System' and 'Operator' Performance Assessment Panels

The 'System' and 'Operator' Performance Assessment panels are similar in function and appearance but are intended for different purposes. The purpose of the 'System' panel is to react automatically to updates in radar parameters and environmental data to maintain a near real-time assessment of current radar capability. In contrast, the 'Operator' panel allows entry of hypothetical radar and threat data and manually initiated FIRMTRAK calculations. The resulting performance plot in the 'Operator' panel can be compared directly to the plot of current capability in the ‘System’ window.

The ‘System’ and ‘Operator’ Performance Assessment panels have “Control” pulldown menus that allow manual initiation of FIRMTRAK runs from either panel. The ‘System’ panel’s “Control” menu additionally allows the operator to open ‘Rocketsonde’ or ‘Floatsonde Launch’ Panels, or to shutdown or reset the SEAWASP system.

Both ‘System’ and ‘Operator’ panels have “Radar,” “Target,” and “Environment” modes. The “Radar” mode contains a Radar Doctrine Window with a layout similar to that of the RSC console in CIC. There are Global and Baseline pages, and eight Sector and Subsector pages. The “Radar” mode also contains a Radar Performance Window containing plots of radar capability based on FIRMTRAK results. These plots are “tied to” the doctrine window such that, as an operator pages through doctrine, the corresponding region in the Radar Performance Window is indicated. A PPI view is shown by default; a range-altitude plot for each sector is available.

Trial doctrine can be entered in the ‘Operator’ Panel by clicking the cursor on a parameter in the Radar Doctrine Window. This opens a secondary window which presents options for that parameter, selectable using radio buttons or sliders. After manually altered parameters are saved, they are identified as “Manual” instead of “AN/SPY- 1” in the Doctrine Window. Modified parameters can be reset to the values active in the cmobat system individually or globally, throughout the ‘Operator’ Radar Doctrine window. Manual configuration of trial radar doctrine is not allowed in the ‘System’ panel since its radar performance plots are intended to always represent current, actual SPY- 1 performance.

The “Threat” mode of both Performance Panels allows the operator to select from a library of threats or define his own constant altitude threat by choosing a radar cross section, altitude, and speed. The “Environment” mode of both Performance Panels presents a plot of the RF propagation factor used in the performance assessment of that panel.

Server Processes of the Radar Performance Assessment Subsystem

A substantial amount of software has been developed to support integrating and controlling SEAWASP’s models, data interfaces, and displays for embedded operation. Primary among these is the Model Server (MS) program. This program handles interprocess communications with the Environmental Data Processor, the HMI, Task Server (TS) programs, and the two server programs that receive ‘live’ radar doctrine: CDCS_Interface Server (CDCSIS), and CEP_Interface Server (CEPIS). The TS programs are responsible for starting and monitoring TEMPER and FIRMTRAK in response to requests by MS. There is one TS process for each processor. CDCSIS is responsible for receiving, processing, and forwarding to MS all SPY-1 doctrine, except for SPY- 1 Sensitivity Time Control (STC) Fence parameters. These data are not passed from SPY to the C&D computer and, therefore, are not available to the CDCS LAN or SEAWASP. The Cooperative Engagement Capability’s (CEC) Cooperative Engagement Processor (CEP) does, however, have access to STC Fence parameters from the SPY computer and broadcasts the data to the CDCS LAN for SEAWASP. CEPIS is responsible for receiving and processing STC Fence messages from the CEP for MS.

MS makes requests of TS for model runs due to three types of events: 1. Receipt of new environmental data from the Environmental Subsystem, 2. receipt of new radar doctrine data from either CDCSIS or CEPIS, and 3. operator requests from the HMI. When new environmental data is received, MS determines which processors is least busy and requests a TEMPER runs from the corresponding TS process. Upon TEMPER’s completion, TS starts FIRMTRAK based on the resultant propagation factor table, using ‘live’ radar doctrine from CDCSIS and CEPIS and selected target parameters from the HMI. Upon FIRMTRAK’s completion, MS passes results to the HMI for display. Likewise, for new radar doctrine data, if CDCSIS or CEPIS indicate that there is a "significant" change in at least one SPY parameter, MS selects a TS to start a FIRMTRAK run based on the new radar parameters and the most recent TEMPER propaga results. Results are again used to create new performance plots.

Operator-initiated performance assessment requests from the HMI result in MS sele . . . . TS, TS starting a FIRMTRAK run based on either 'live' or trial radar doctrine, and the HMI displaying results of the FIRMTRAK run.

Additional capabilities being implemented into SEAWASP provide for robust embedded operation. These capabilities include monitoring the health of processes, restarting failed processes, gracefully shutting down the system when power is switched off or is lost, and displaying additional fault messages on the HMI.

Field Test Experience

The following summarizes the test periods to date:

September 1993	Puerto Rico & Mid-Atlantic Coast	CG71	13 Days
April 1994	Mid-Atlantic Coast	CG 68	10 Days
June 1994	Puerto Rico	CG 68	9 Days
October 1994	Kauai, HI	CG 73	19 Days
February 1995	Arabian Gulf & Gulf of Oman	CG 70	14 Days
Current	Mid-Atlantic Coast	CG 68 &71	Ongoing

The first three periods focused on automated environmental characterization. The tested system automatically collected and processed environmental data and computed propagation factors for SPY- 1 radar parameters. Testing the Radar Performance Assessment Subsystem began during the October 1994 period. The latest SEAWASP version, presently installedonCG68andCG71, will remain on board these cruisers until at least Fall 1997.

Figure 5 presents raw rocketsonde and processed composite refractivity profiles form 19 October 1994; these data were collected and processed aboard CG 73 while on the Pacific Missile Range Facility (PMRF), Kauai, Hawaii. The smoothing/filtering performed by the Environmental Data Processor is clearly evident. This processor also merged a 22-meter evaporation duct profile with the smoothed rocketsonde profile. As it happens, however, the atmosphere was marginally stable and the rocketsonde profile partially captured the evaporation duct profile shape. For this reason, the merging process is not obvious in Figure 5. Figure 6 focuses on the first 200 feet of the profile, and the impact of the merger is more visible. For this case, the algorithm discards the lowest three points of the rocketsonde data, then gradually transitions from the modeled evaporation duct profile to the rocketsonde profile. This transition occurs between the duct height (22 ft) and twice the duct height (44 ft). Note that the nominal 10-to-12 foot resolution of the rocketsonde only permits 2 or 3 samples in an evaporation duct of this size. However, the good agreement between the modeled and measured profiles for the evaporation duct is encouraging.

For this particular condition, the small features in the rocketsonde profile, such as the small elevated layer at approximately 80 feet, significantly impacted the AN/SPY-1 firm track range predictions. Our experience has been that this is generally the case in all areas where we routinely conduct tests, with the exception of Puerto Rico, where knowledge of the evaporation duct alone often provides a good performance estimate.

Another type of verification test of the shipboard sensors was performed in June 1994 on the Atlantic Fleet Weapon Test Facility (AFWTF) near Puerto Rico. During this time, SEAWASP was on CG 68 and JHU/APL also had a fully instrumented civilian boat as close to the AEGIS cruiser as safety would permit. The instrument environment on board the civilian boat was more advantageous than that of CG 68, and the civilian boat also had additional sensors at various heights. Throughout the tests, the evaporation duct estimates from the two systems agreed to within 1 meter of each other. This agreement suggested that, at least for the environments and ship behavior experienced during this period, the SEAWASP sensors were avoiding contamination from the ship environment.

The true tests of SEAWASP's effectiveness from the end-user's point-of-view occur when well-characterized, controlled, low-altitude targets are presented to SEAWASP-equipped ship. During the test events listed above, four low-altitude drone events and eight controlled manned aircraft events took place. In each case, SEAWASP firm track range estimates agreed with the observed performance with an error of less than 10%. These events included instances when the firm track range was doubled due to ducting. The authors recognize that these events still represent a statistically small sample, but every effort will be made to take advantage of future controlled target opportunities.

Finally, throughout the various shipboard tests, feedback has been solicited from the SPY-1 operators and other ship's personnel regarding the user-friendliness of SEAWASP and the various HMI features. The SEAWASPs ystem was also presented to the AEGIS Training Center (ATC) at the Naval Surface Warfare Center/Dahlgren Division (NSWCDD). These exposures to the Navy's operational and training communities produced both strong support for the SEAWASP approach and excellent suggestions for improvements. When feasible, the suggestions have been incorporated in subsequent versions of SEAWASP. As previously mentioned, the current version is aboard CG 68 and CG 71, and it will deploy for the first time with these ships without engineering support. This deployment will test the robustness of the environmental instrumentation and computer hardware, the reliability of autonomous software. and long-term ease of use by ship operators.

Future Work

The following is a partial list areas where SEAWASP and other shipboard assessment systems would need development to support a variety of extended performance assessment capabilities including area defense and littoral operation:

1. Incorporation of high-fidelity land and sea clutter models - This will also require some clutter model development and validation. Integration of rudimentary sea clutter models and land blockage algorithms into SEAWASP are planned for late 1997.

2. Implementation of interfaces to the Naval Integrated Tactical Environmental System (NITES) via the Joint Maritime Combat Information System (JMCIS) - The purpose is for SEAWASP to have access to, and to contribute to, environmental data being distributed through the fleet, and NITES/JMCIS is the Naval Oceanographer's method for doing so. This work will be completed for SEAWASP in the next 1-to-2 years.

3. Assimilation of data from other sources (particularly data that maybe available from NITES/JMCIS) - This problem is particularly challenging due to the variety of potential data sources which use different environmental quantities, and have different levels of accuracy, timeliness, and resolution. The Naval Research Laboratory in Monterey is presently working in this area. A simpler sub-problem is to accommodate range- and azimuth-varying environmental information of the same type. Such algorithms would be employed, for example, if SEAWASP data were passed to other SEAWASP-equipped ships via the Cooperative Engagement Capability Data Distribution System (CEC DDS).

4. Automation of AN/SPY- 1 doctrine recommendations - The current version of SEAWASP requires the operator to employ trial-and-error in determining the best radar settings (using the Operator Performance Assessment Panel). This feature performs an intelligent search over the appropriate radar parameters and develops a recommended radar setup. An initial capability is

planned for 1997 with follow-ons over the next 2 years.

5. Development and integration of new remote sensing and environmental modeling approaches - A particularly important goal of such advances is to reduce, or eliminate, the requirement for expendable; for SEAWASP these include rocketsondes and floatsondes. The Navy, other US services, and the civilian remote sensing community are working in this area, but significant progress is likely to be long-term. However, approaches using lidars for atmospheric profiling hold considerable promise.

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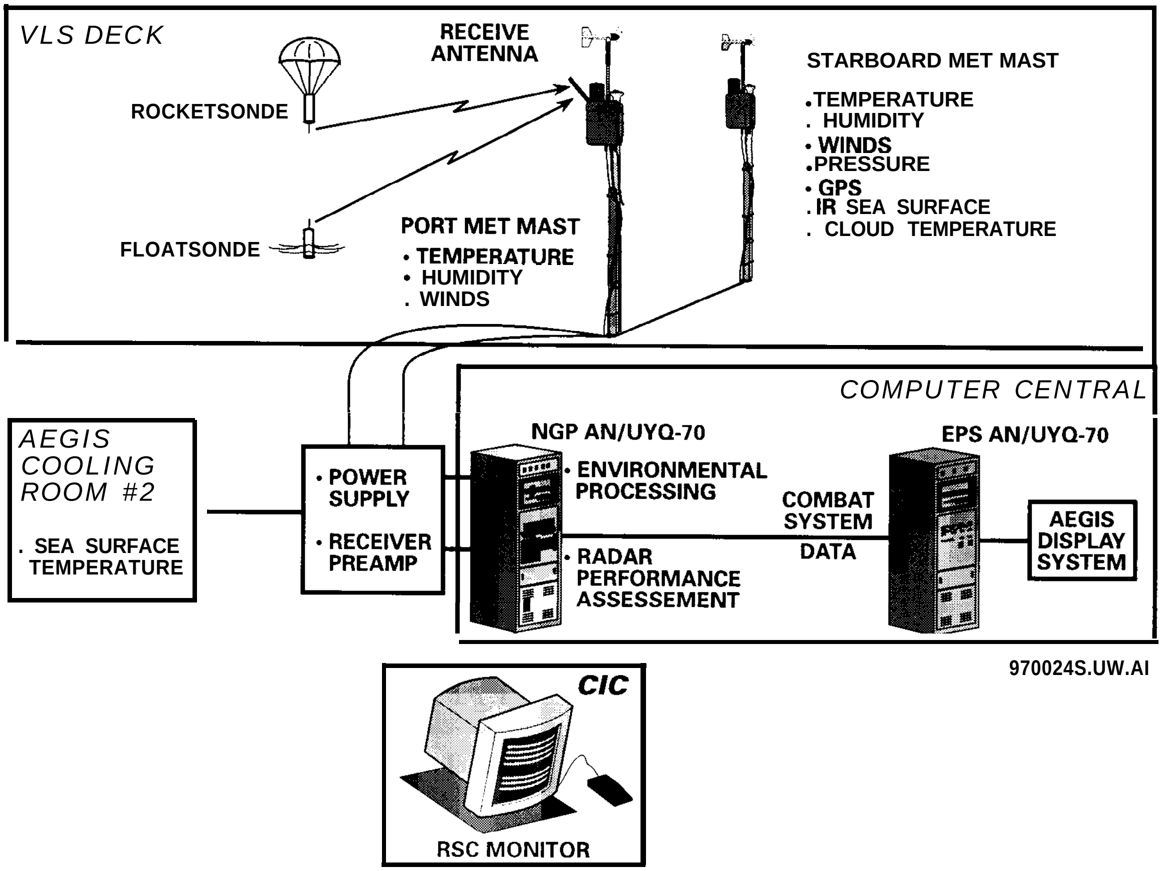

Figure 1. Overview of SEAWASP System Layout

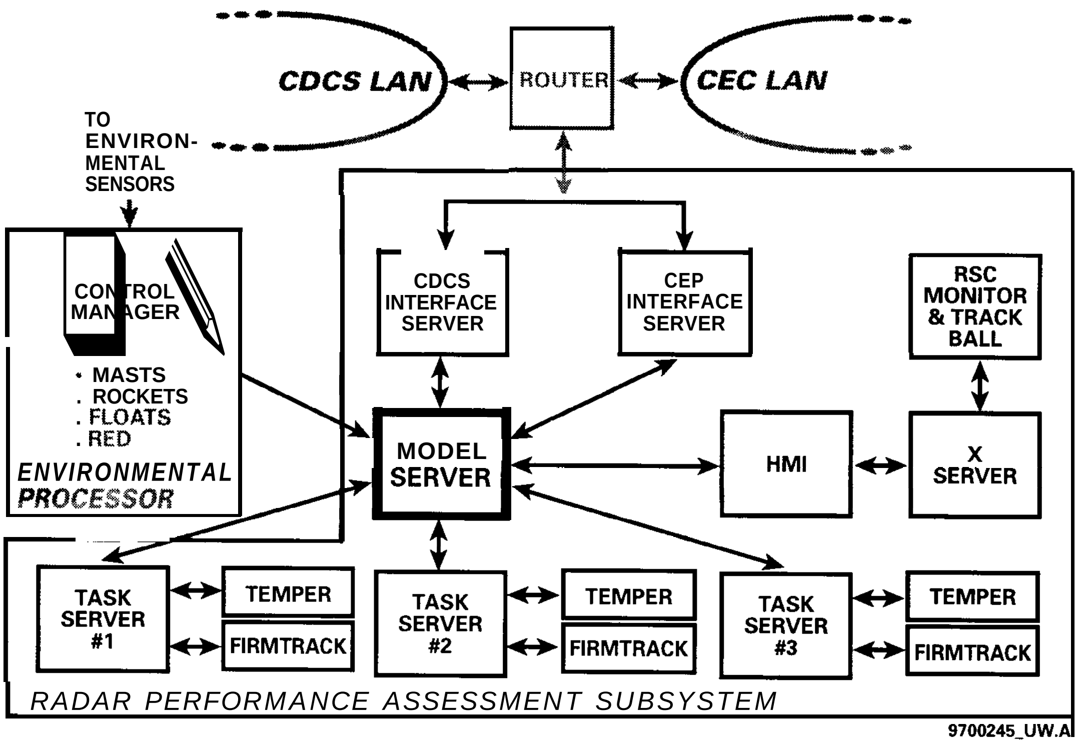

Figure 2. Radar Performance Assessment Subsystem Software Architecture

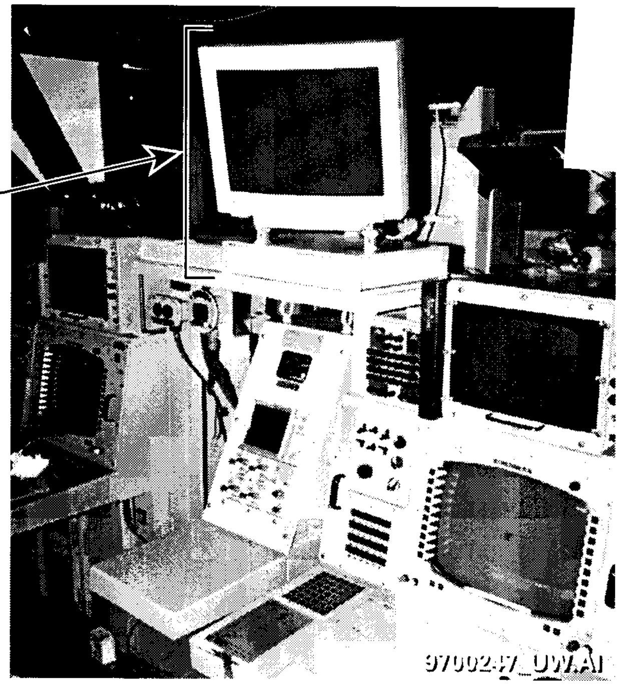

Figure 3. SEAWASP X-Station Near SPY RSC Console in **CIC** of CG68

Figure 4. **SEAWASP** Human-Machine Interface Display.

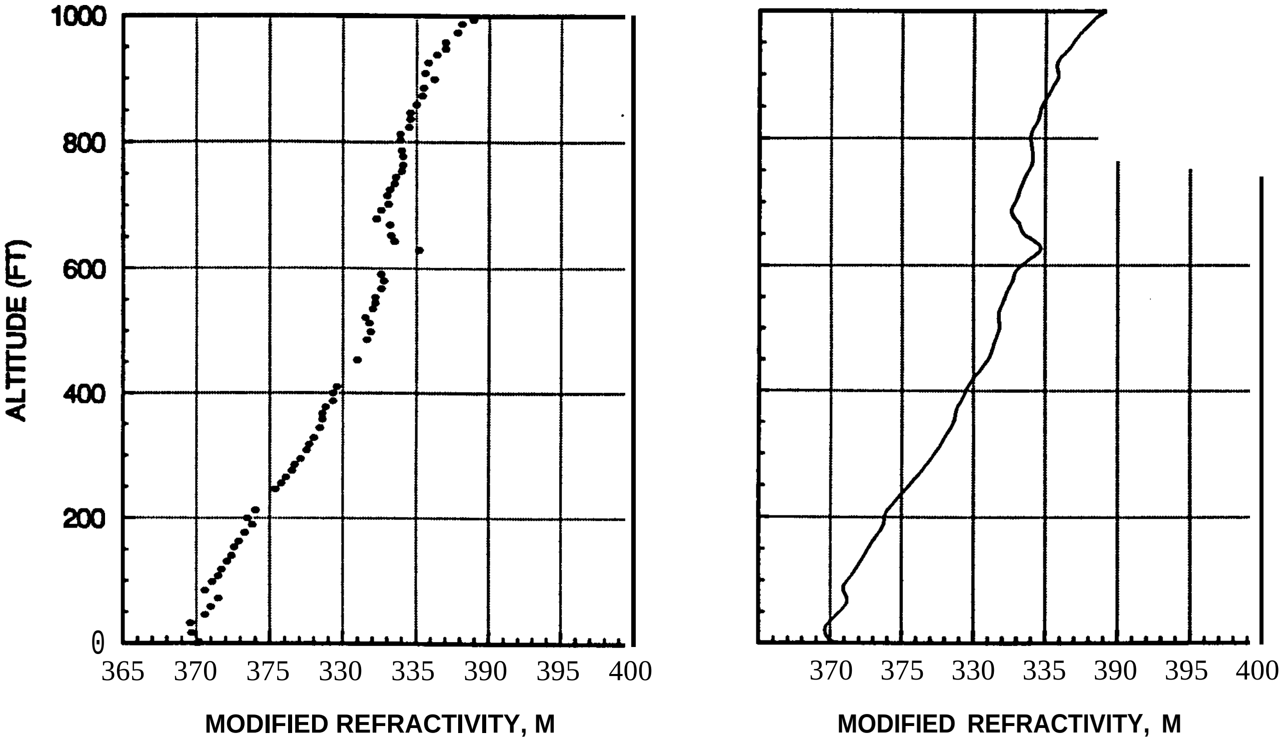

Figure 5: Raw rocketsonde and composite refractivity profiles from CG 73,19 October 1994

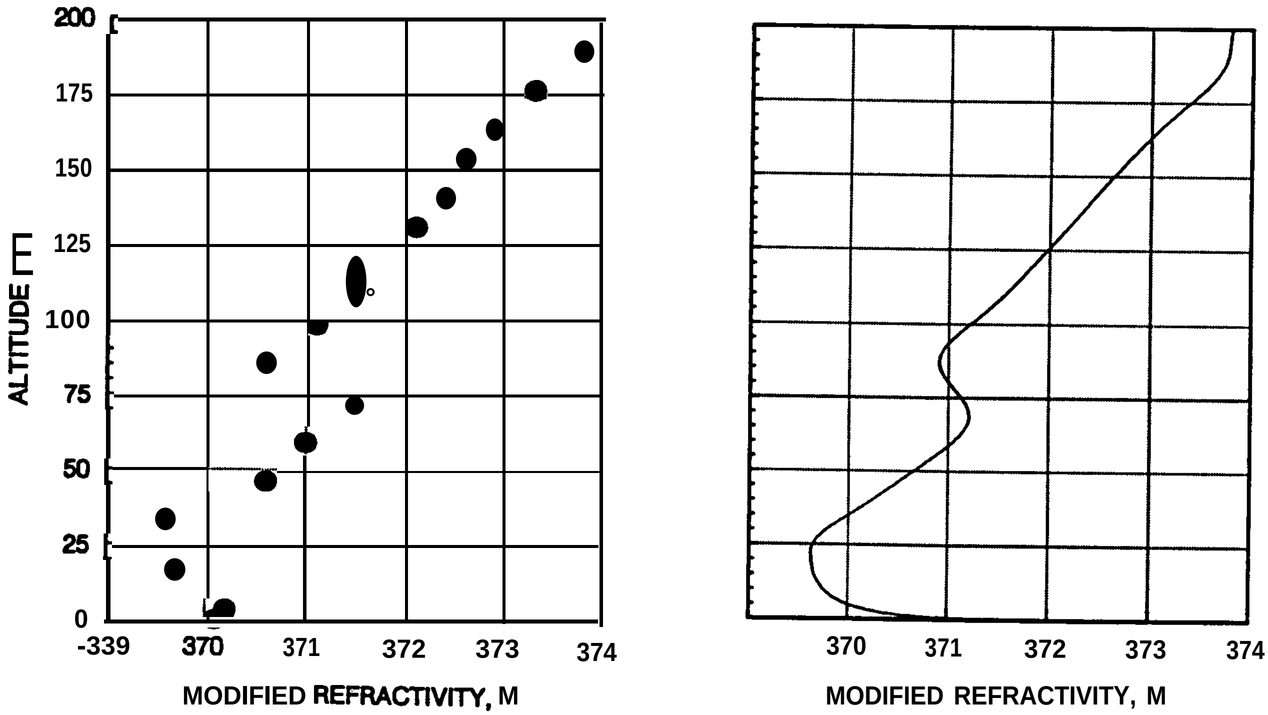

Figure 6: Expanded view of refractivity profile from CG 73, 19 October 1994